Meteorological Measurements for Solar Energy

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Qualification
Solar Energy Meteorology

Overview

Meteorological measurements for solar energy

- Introduction:
  - Solar energy options
  - Solar energy meteorology and its relevance for solar power plants

- Presentation of meteorological parameters that help solar power and their measurement

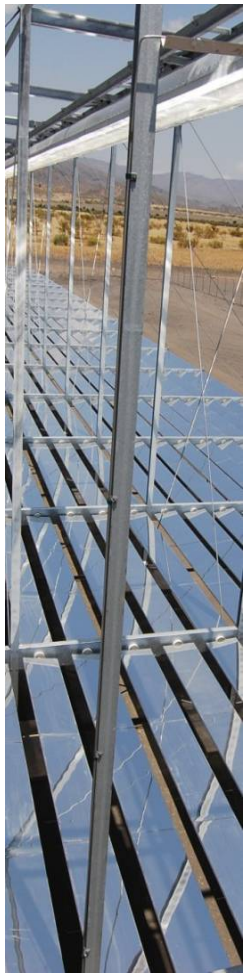
Photovoltaic (PV) power plant options

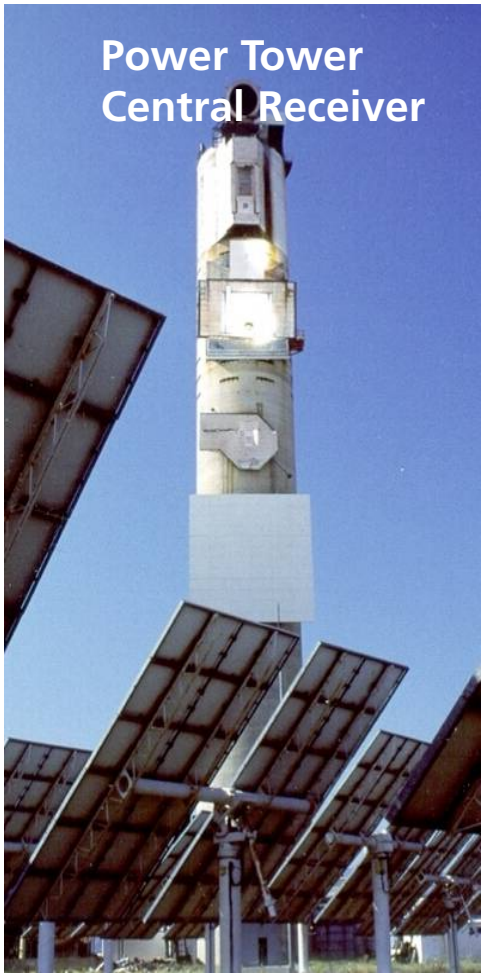
- Different cell types
- Fixed tilt, 1 or 2 axes tracker
- Concentrating PV (CPV)

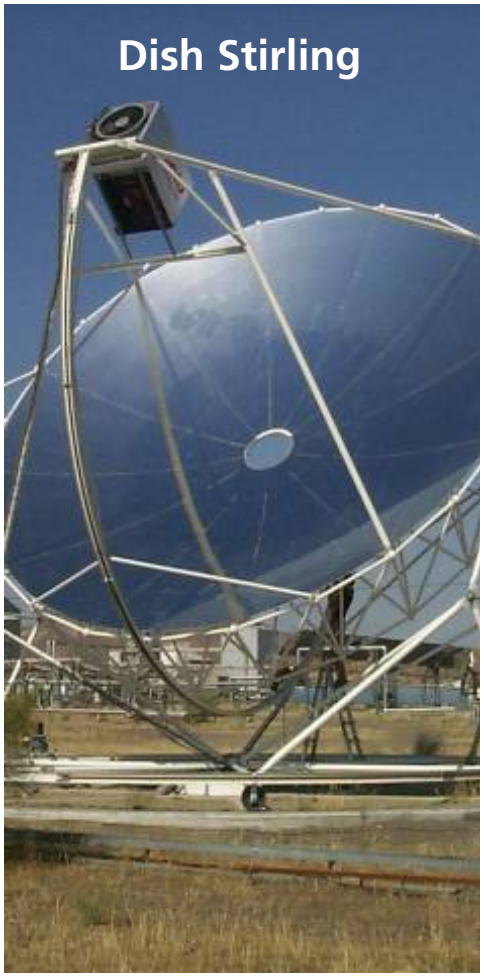
CPV images: Hirsch, T., N. Martin, L. Gonzalez, M. Biencinto, S. Wilbert, M. Schroedter-Homscheidt, F Chenlo, and J.F. Feldhoff. 2014. Technical report on the functional requirements for the nowcasting method. Report D2.1, FP7 project DNICast, Grant Agreement No. 608623.: DLR, CIEMAT.

Concentrating Solar Power (CSP) technology options

- Electricity and/or heat





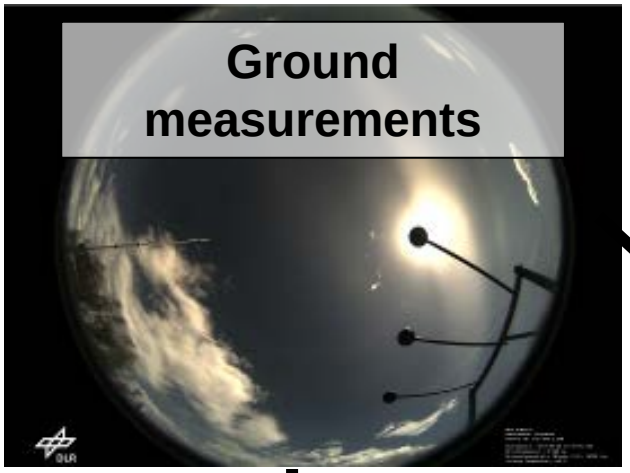


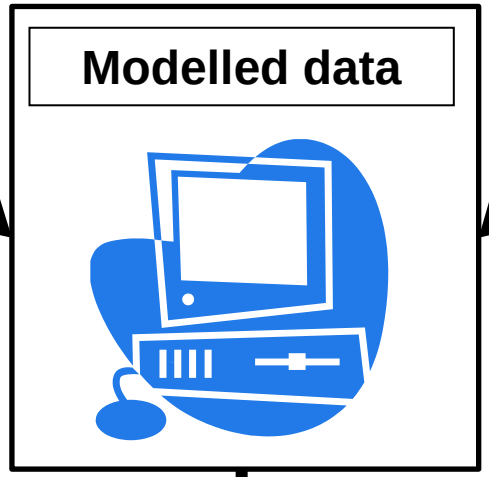
Other solar energy technologies

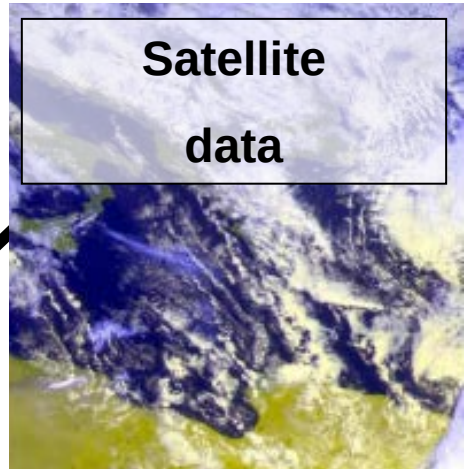
- Flat plate collectors for heating and cooling
- Collectors for solar water treatment
- …

Images: CIEMAT, psa.es

Solar energy meteorology







Prediction of plant yield

- long term yield of future plant
- behavior & yield of existing plant

Application:

- Site selection
- Site specific plant layout
- Optimal decisions during plant operation

Meteorological parameters relevant for solar plants

Parameters

- GTI (Global Tilted Irradiance)
  and/or DNI (Direct normal irradiance)
  - *Circumsolar radiation*
  - *Spectrally resolved*
- Wind speed, direction and gust
- Temperature, humidity, pressure
- Soiling rate, dew, snow, rain
- *Extinction between heliostats and receiver*
- UV, salt concentration, abrasion

➢**Historical and live meteo data & forecasting required for bigger plants**

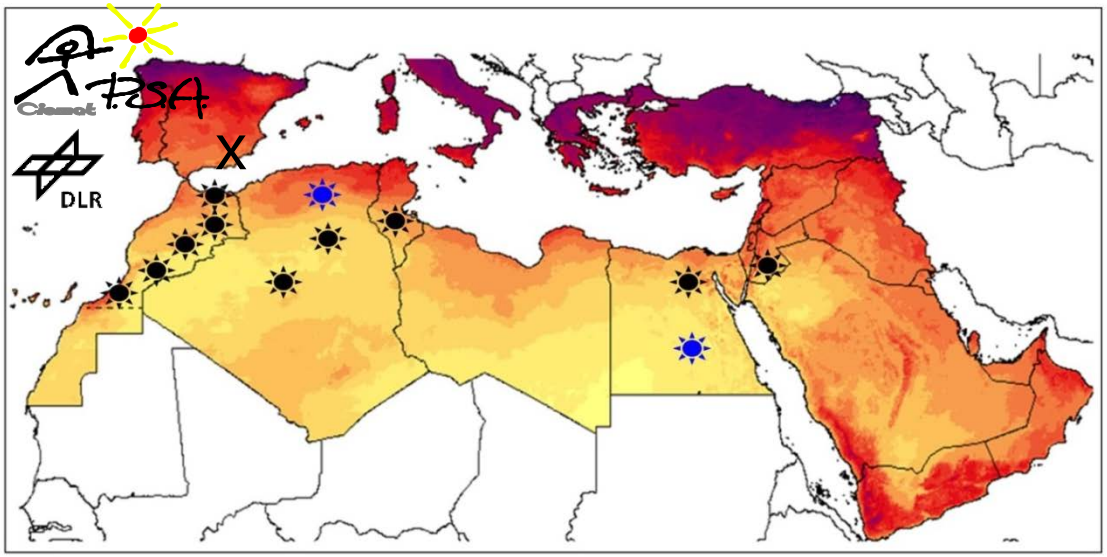
Meteo data collection not a burden, but a chance for energy cost reduction

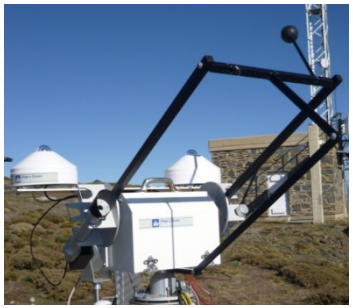
- Low data uncertainties reduce financial risk and financing costs!
- Cost reductions due to smart site specific design
- Cost reductions due to optimized operation (live data, forecasting → yield ↑)

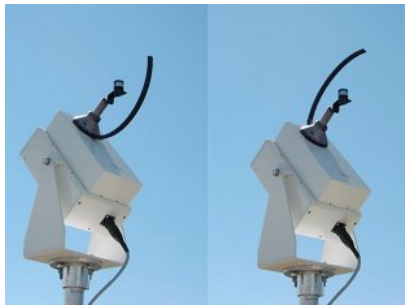
Solar radiation measurements

Solar radiation measurements

Satellite derived data **and** ground measurements are required for MW+ plant projects
- to reach the required accuracy for historic long term data
- & for the plant operation.

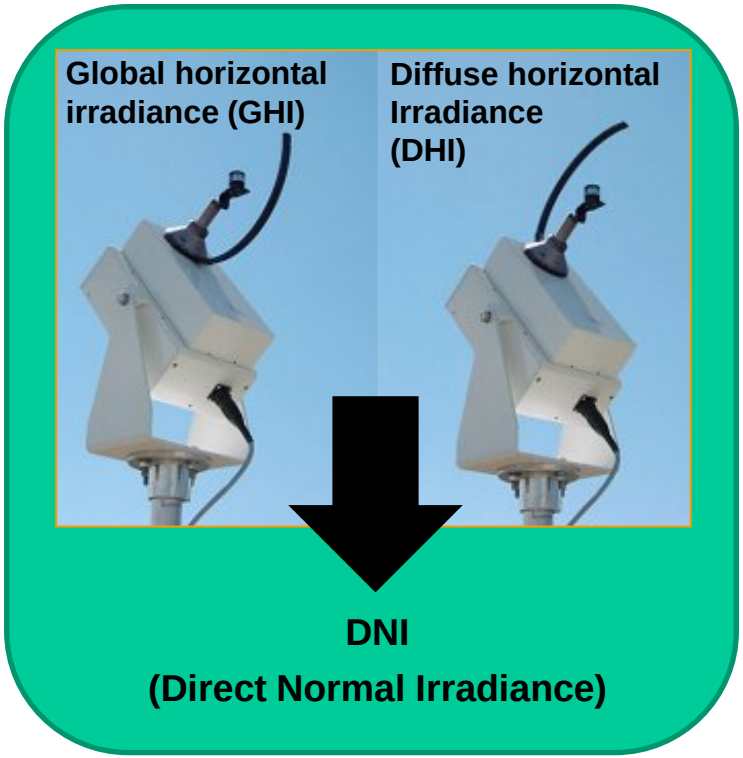






DLR

Solar radiation measurements
Rotating Shadowband Irradiometers



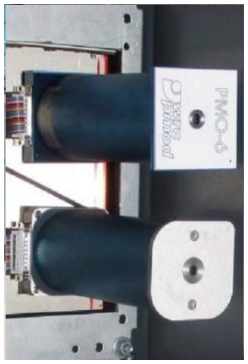
Principle of operation

1. Pyranometer measures global irradiance
2. Shadowband rotates once per minute
3. During rotation:
   measure the
   diffuse irradiance

→ DNI is calculated
→ GTI calculated

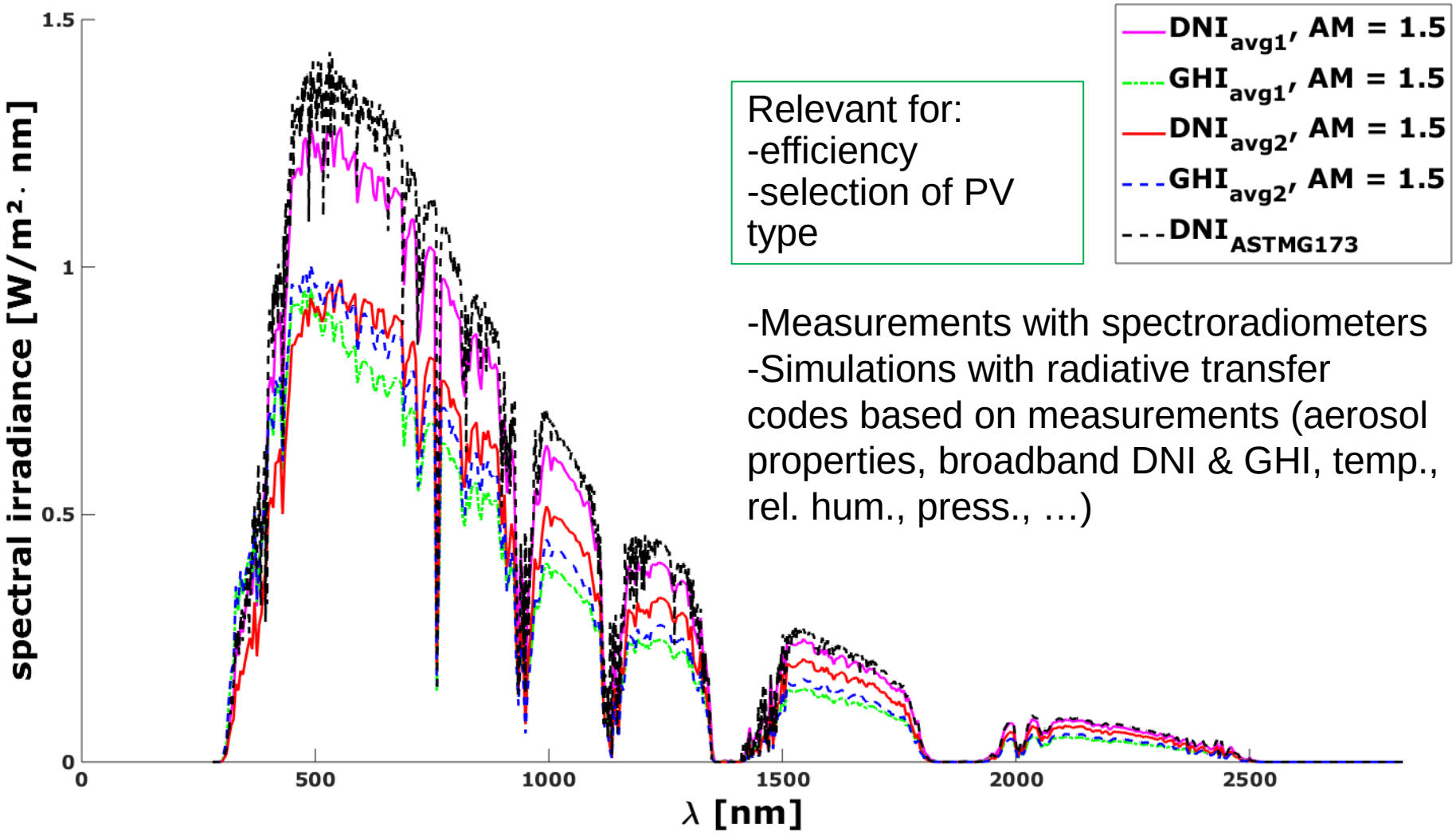
- Robust instrument used for solar resource assessment at remote sites
- Characterization, further improvements & calibration

Instrument calibration and characterization



-Calibration is the greatest uncertainty source of common radiometers
-Enhancement of calibration techniques
-Evaluation of systematic errors and accuracy
-Correction functions for systematic errors
-Calibration of Si-sensors & RSI

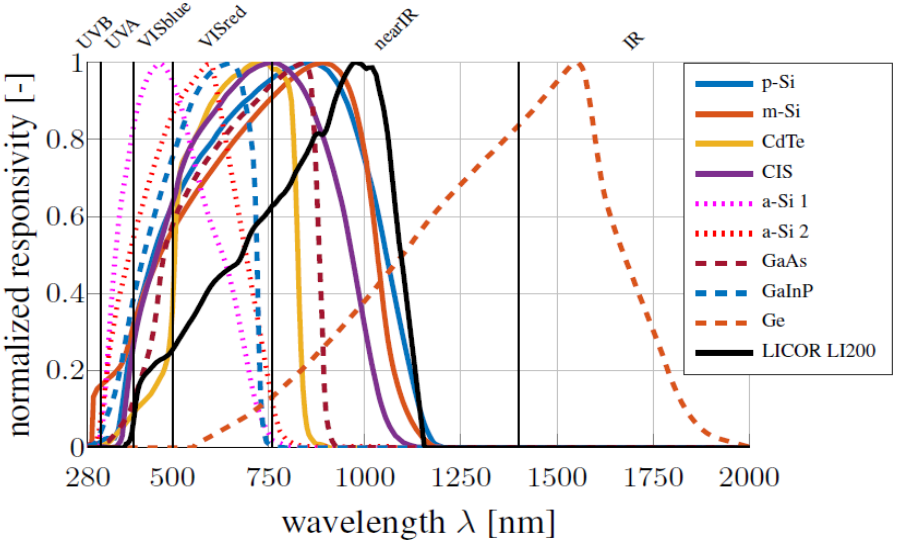
Solar spectra

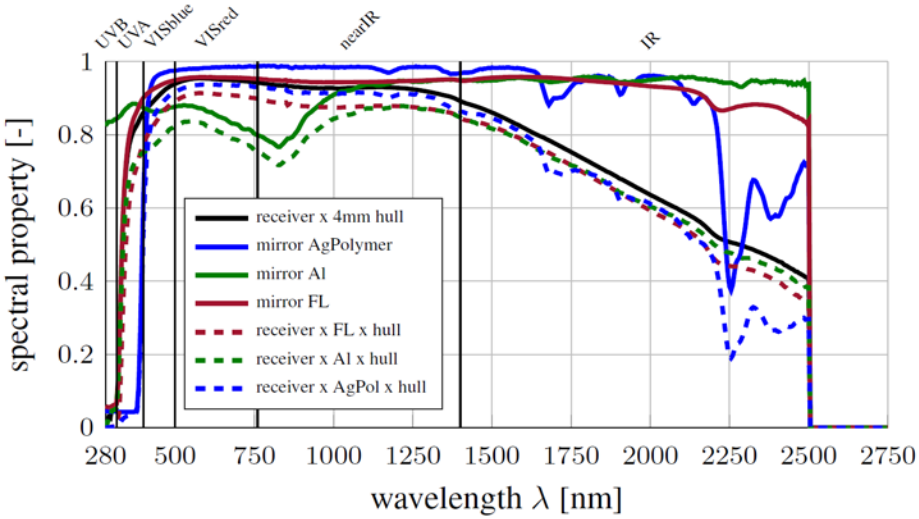


Relevant for:
-efficiency
-selection of PV type

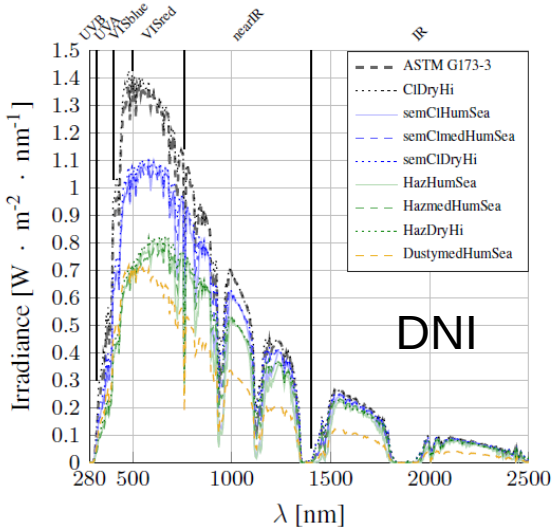
-Measurements with spectroradiometers
-Simulations with radiative transfer codes based on measurements (aerosol properties, broadband DNI & GHI, temp., rel. hum., press., …)

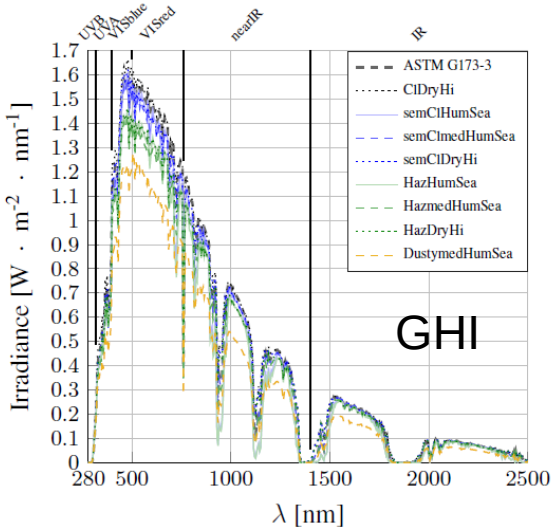
Spectral effects on solar technologies and radiometers





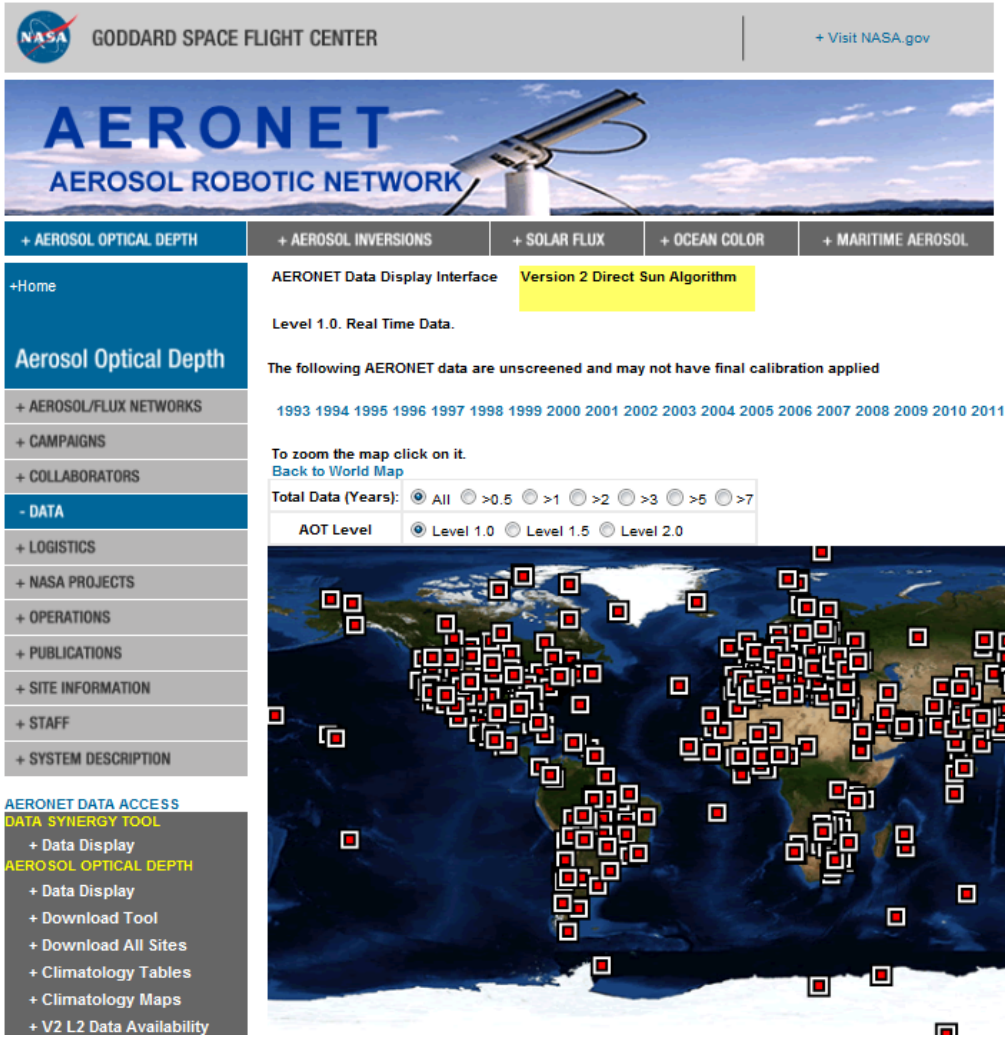
-spectral effects on PV and Si pyranometers must be considered for yield analysis



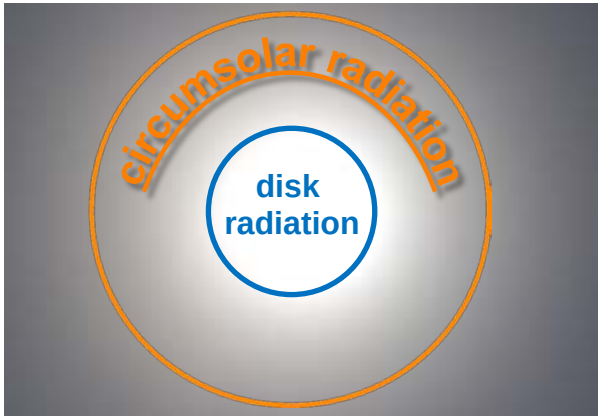


Sun photometers

- Measurement of aerosol properties
- e.g. NASA's AERONET
- reference for satellite based aerosol measurements



Circumsolar radiation



- Circumsolar radiation is forward scattered solar radiation
- **Concentrating collectors use:**
  nearly the complete disk radiation
  +
  a smaller fraction of the circumsolar radiation

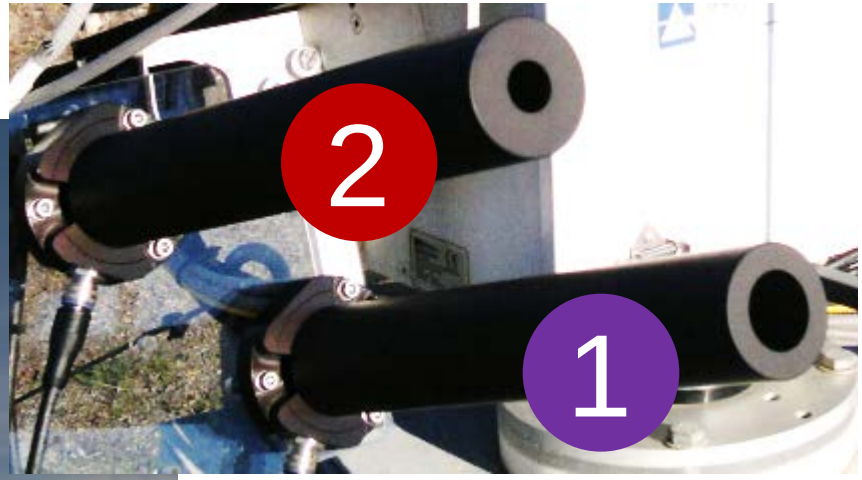
Relevant for:
-operation and plant output
-design of plants (field size)
-selection of solar technology

Measurement of circumsolar radiation – SFERA system

- SAM (Sun & Aureole Measurement), software (+ optional sun photometer)
  - camera based system @ 670nm
  - broadband radiation needed for CSP, spectral radiation for CPV

- master-system running at PSA
  - 2 replicas: CNRS/Odeillo (France), Masdar Institute (United Arab Emirates)

Circumsolar Radiation Sensor using pyrheliometers

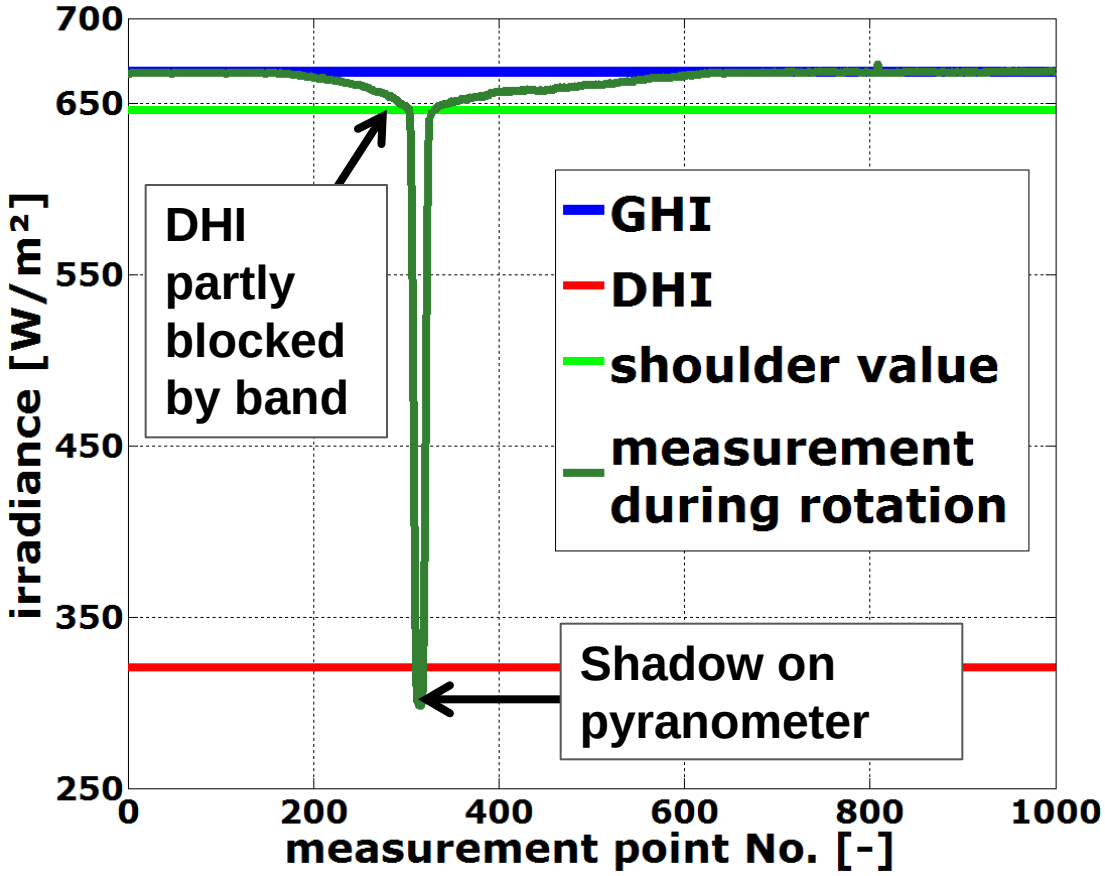


Black Photon Instruments

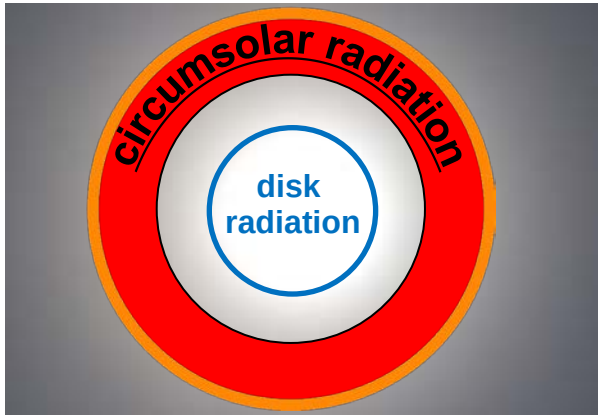
Circumsolar radiation measurement with RSIs

Circumsolar radiation measurement with RSIs

- Algorithm analyses measurement during rotation
- No additional hardware required



Circumsolar contribution from 1° to 3.2° measured with an RSI

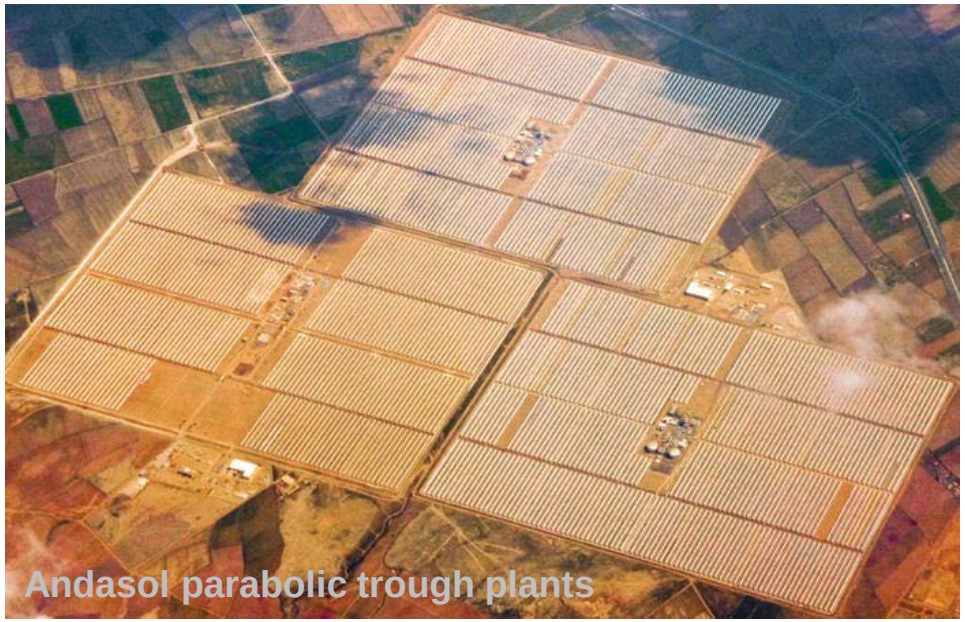


Variability of irradiance & forecasting

Variability of irradiance & forecasting

Forecasting and temporal and intra-plant-spatial variability are relevant for:

- -PV production ramp rate control
- -PV back up system control (diesel generator)
- -CSP&PV plant yield optimization (e.g. market participation)
- -CSP & PV plant design (storage size)
- -selection of solar technology depending
- -grid operation



Andasol parabolic trough plants

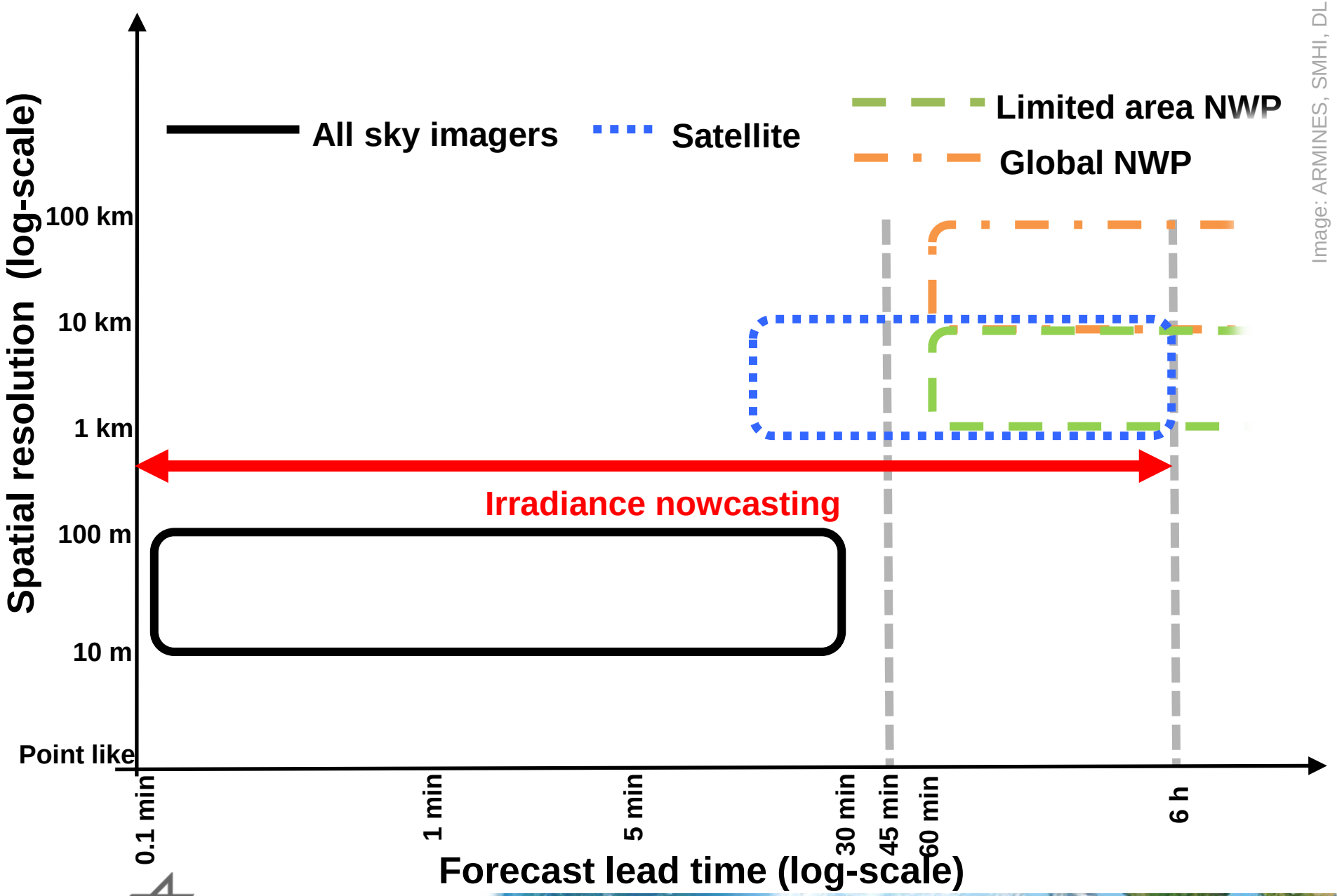
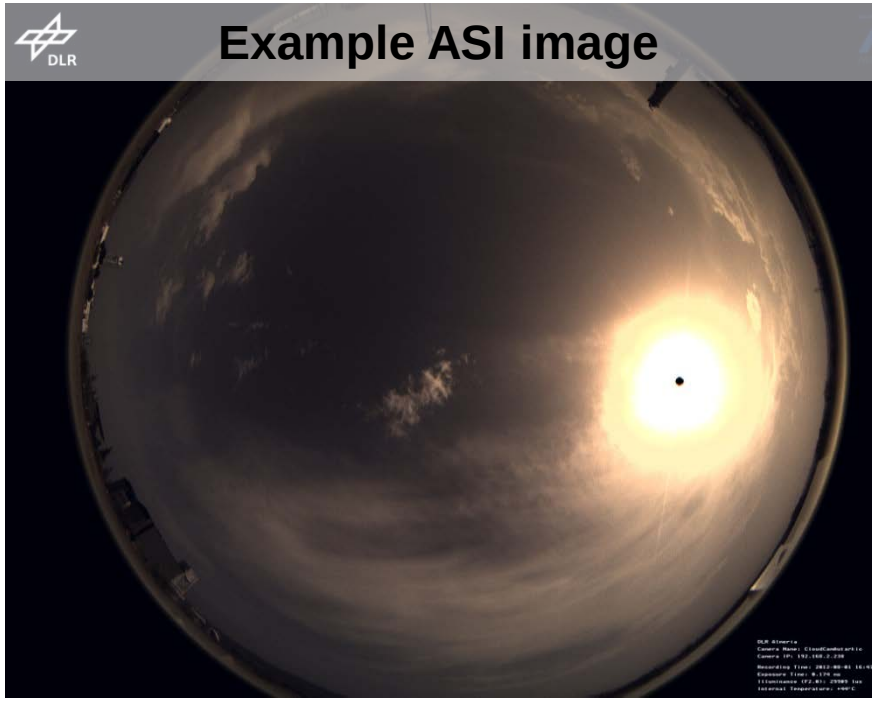


Image: ARMINES, SMHI, DLR

All sky imager (ASI) based irradiance nowcasting

- Spatially resolved DNI, GTI, GHI maps with high temporal resolutions
- Combination with NWP (numerical weather prediction) and satellite nowcasts



Working principle of ASI based nowcasting systems

ASI cameras film clouds

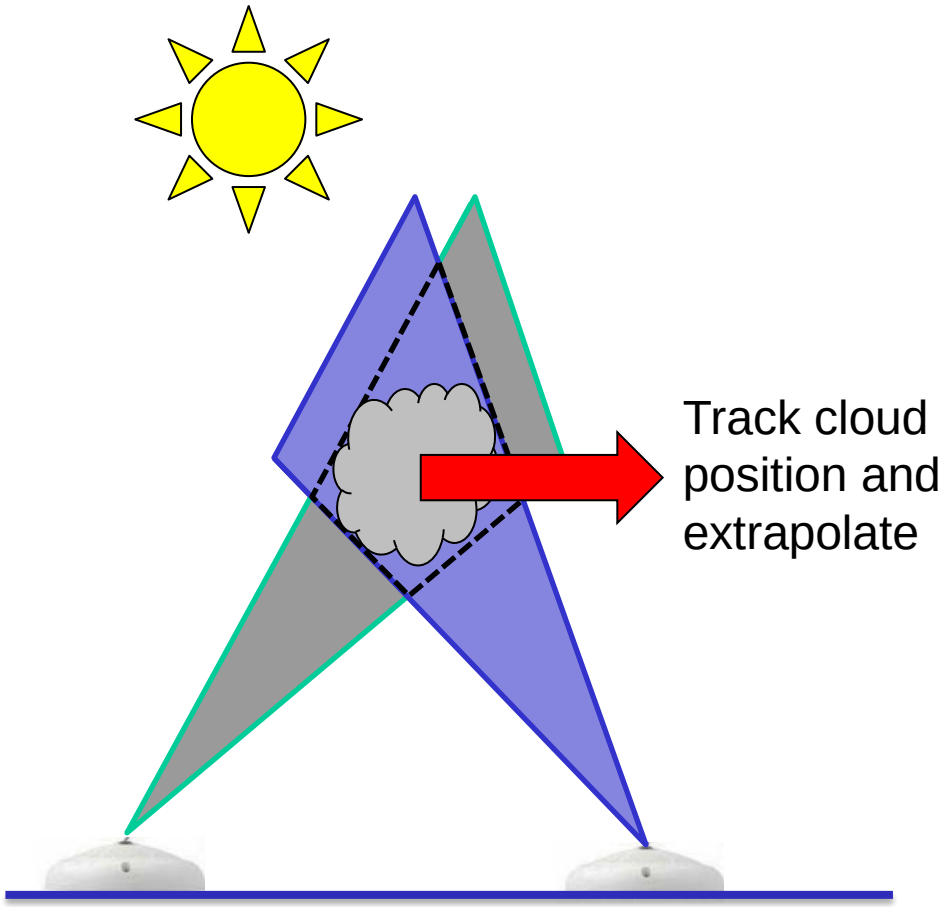
Clouds are segmented

Clouds are geolocated

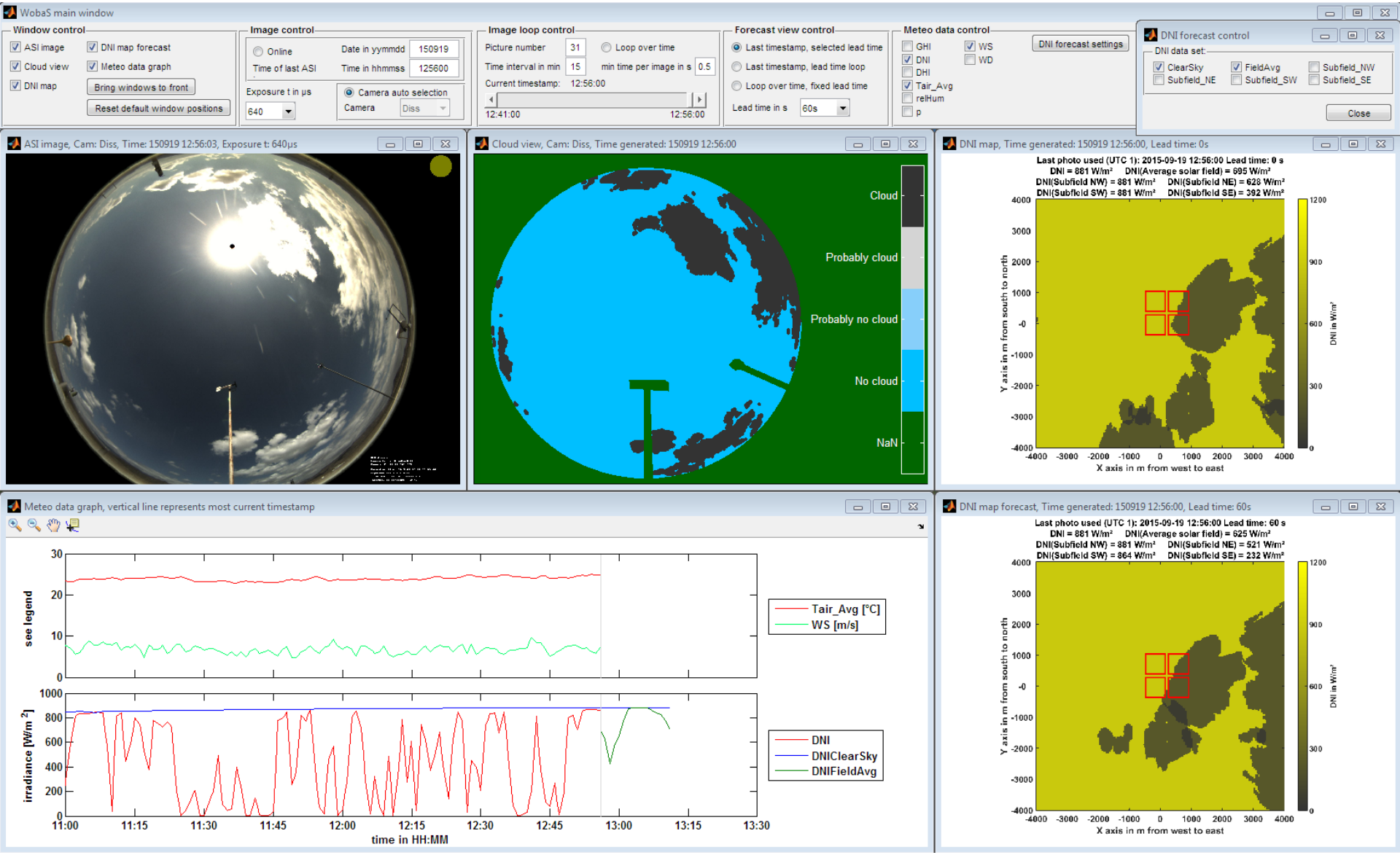
Shadow map is estimated

Sensors provide irradiance data

Irradiance map is created



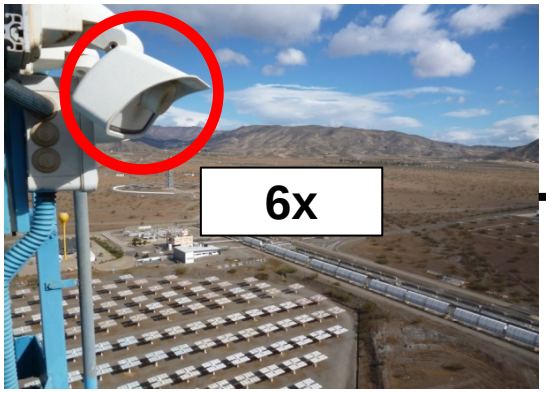
User interface of a nowcasting system (WOBAS)

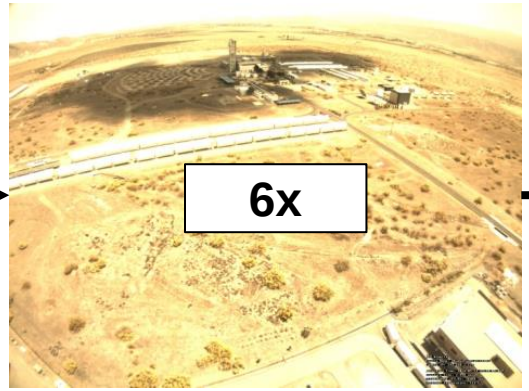


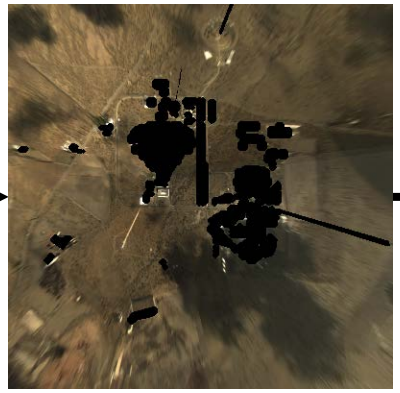
DLR

Radiometer and ShadowCam-system

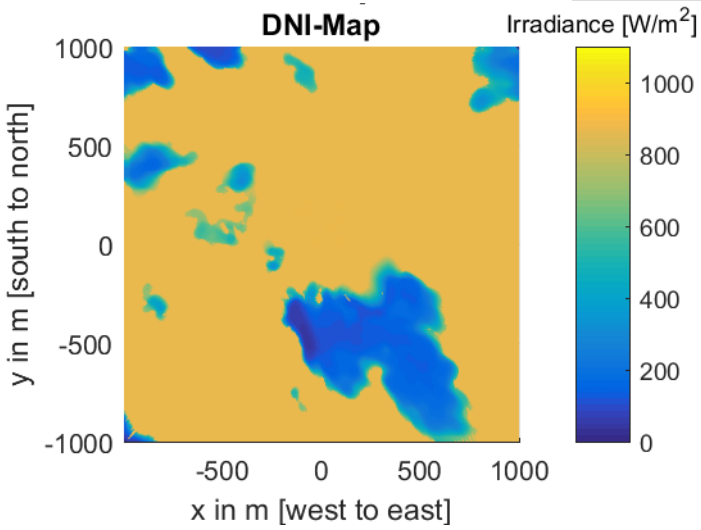
Ground-filming cameras provide irradiance maps

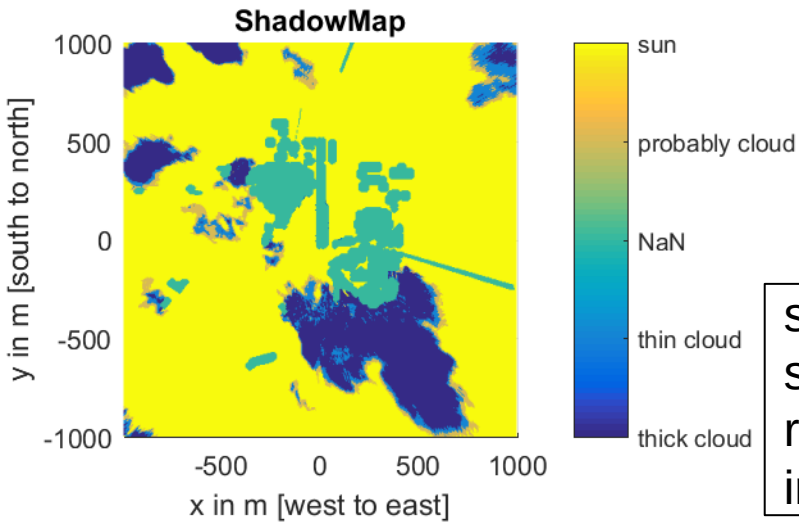






radiometers

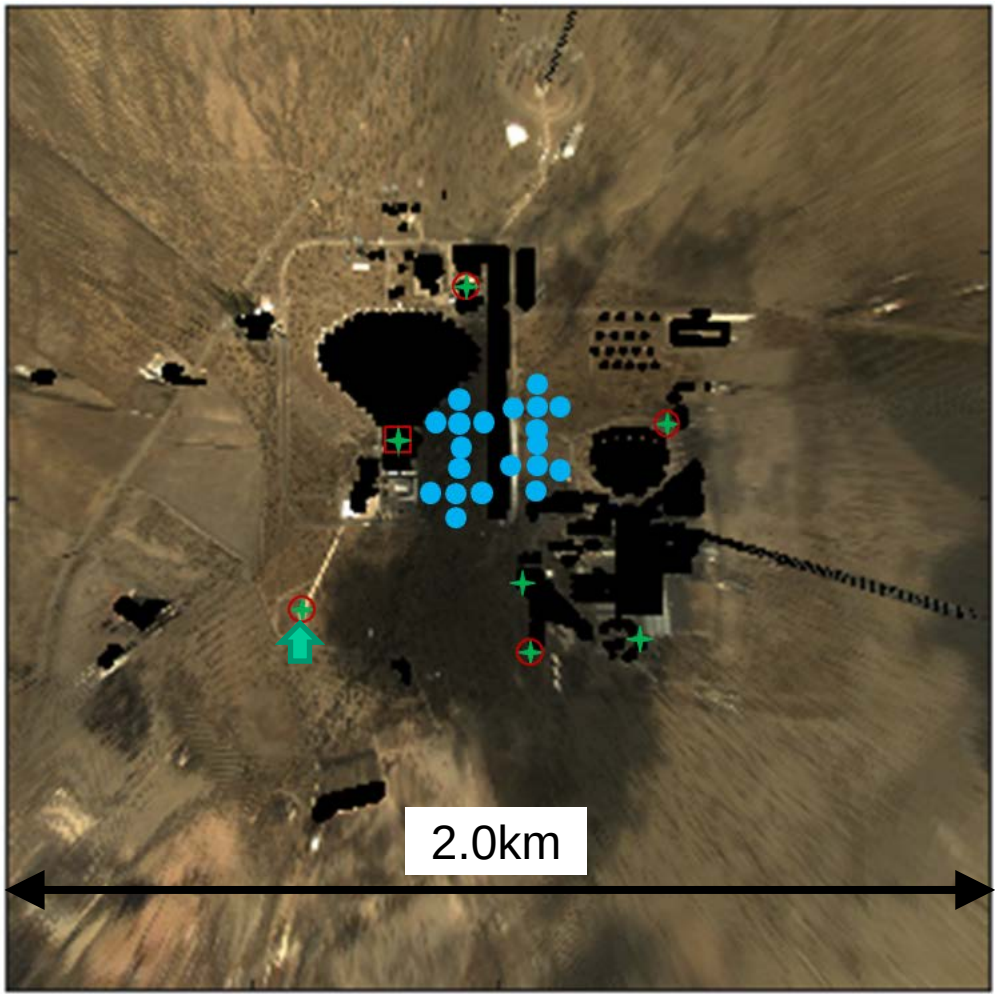




sunny + shaded reference image

Radiometer and ShadowCam-system

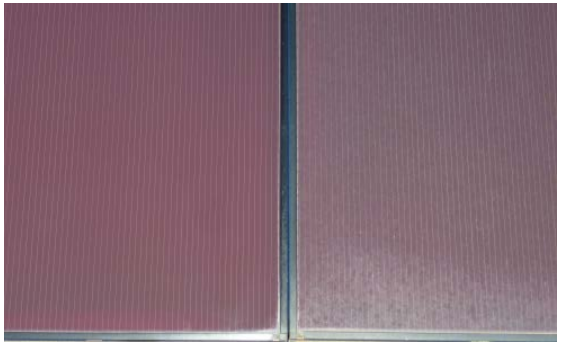
- 4 Q24 ASI (All Sky Imager)
- 6 M25 ShadowCams
- 20 Si-pyranometers
- Pyrheliometers + pyranometers
- Ceilometer



Soiling

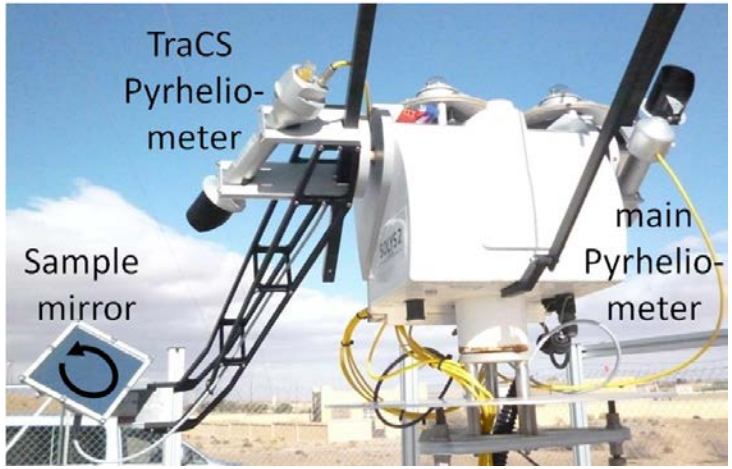
Soiling

Relevant for:
-operation and plant output
-When do we have to clean?
-plant design, site selection

Soiling measurements for PV modules and reference cells

CSP-specific soiling measurements with TraCS or handheld reflectometers



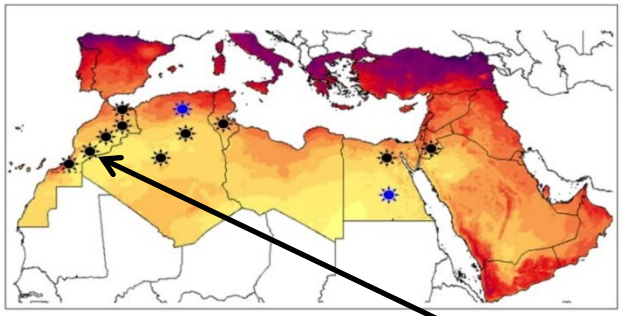

Soiling modelling based on simple measurements
Dust sampling

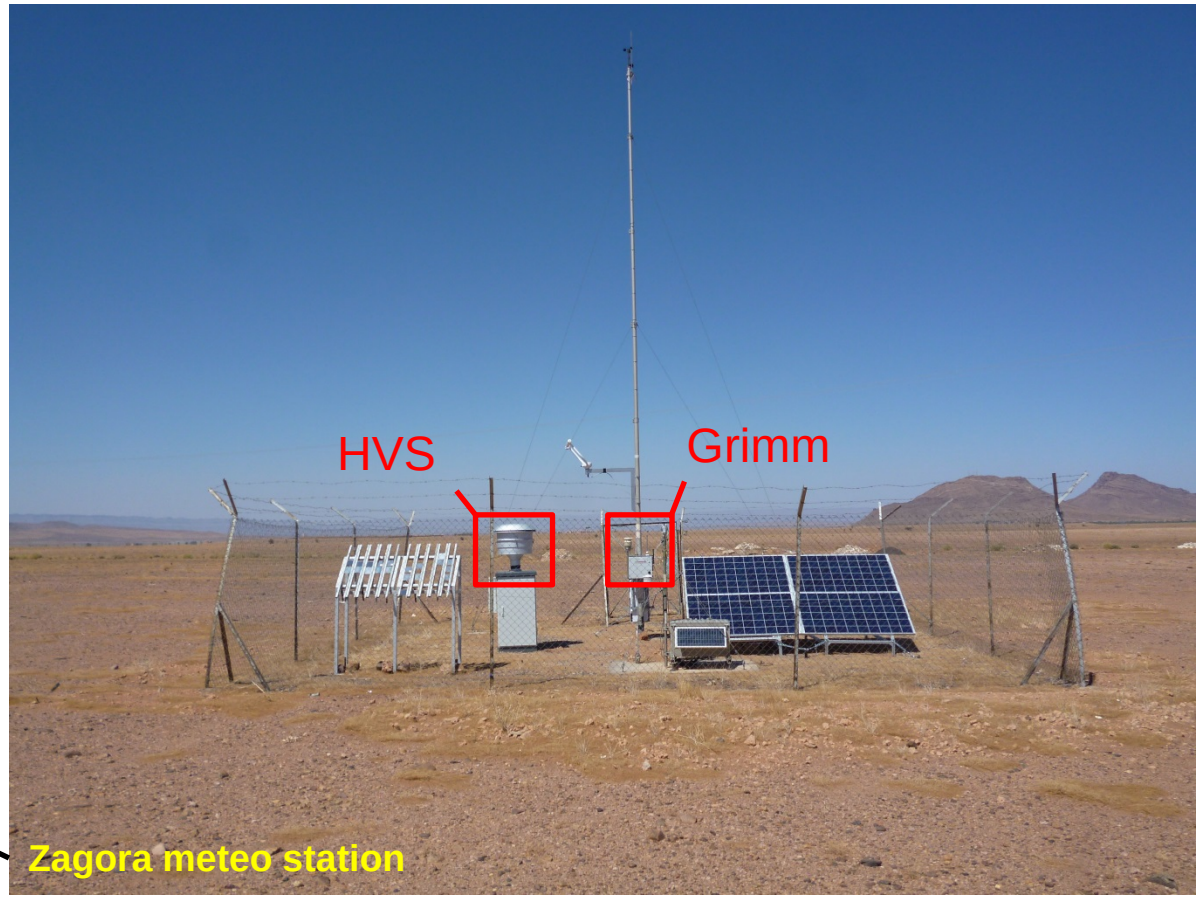
Optical systems, e.g.:

- Scatterometer type

Gravimetrical system

- Filter in air flow





Beam attenuation between heliostat and receiver

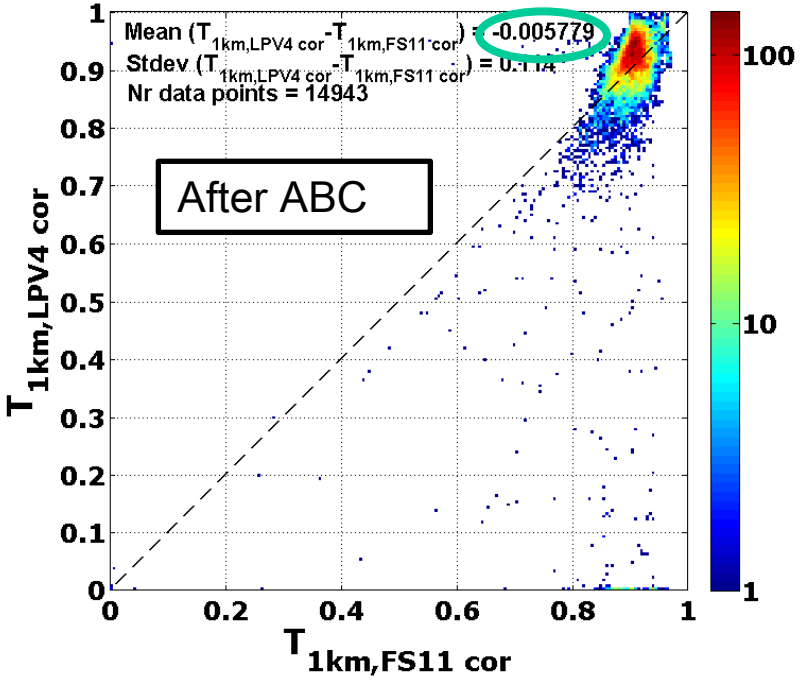
Beam attenuation in tower plants

Relevant for:
-design of tower plants (field size)
-selection of solar technology
-operation and plant output

Beam attenuation in tower plants

Vaisala FS11 scatterometer

Optec LPV-4 transmissometer



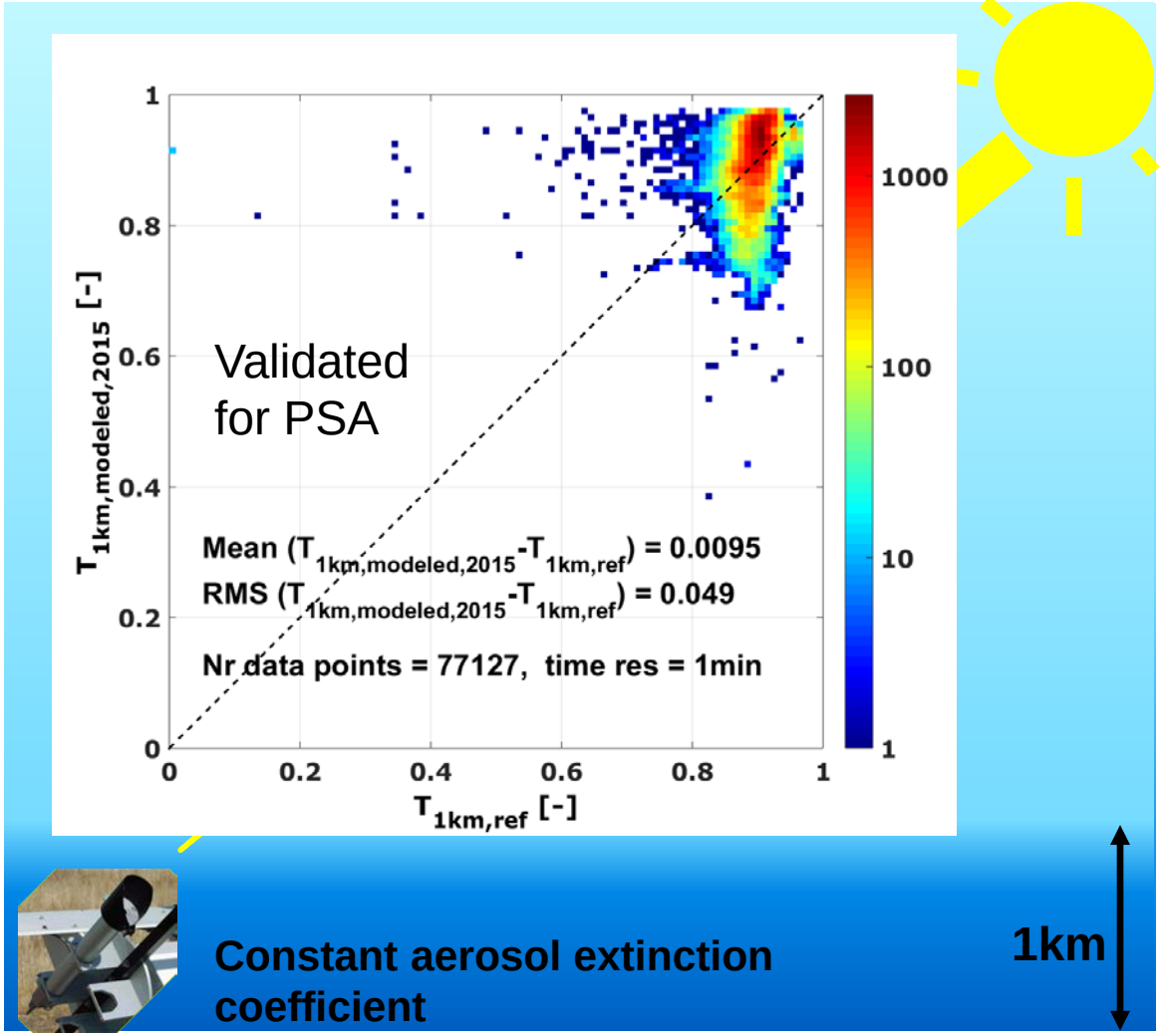
ABC improves coincidence between both sensors!

Commercially available instruments applicable for CSP if ABC correction is applied!

Extinction modelling based on DNI measurement

Compare clear sky DNI measurement with modelled DNI for aerosol free atmosphere
+
Assumption about aerosol height profile

→ Calculate extinction coefficient close to ground



Parameters affecting durability

Parameters influencing durability

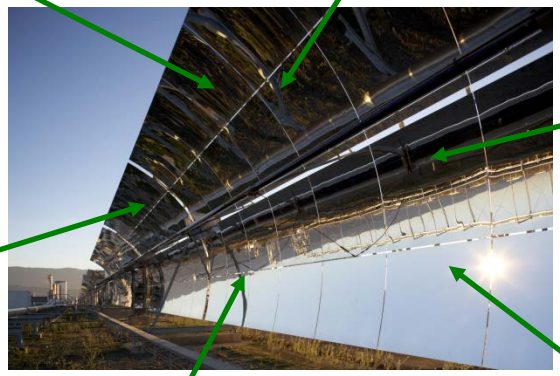
Relevant for:
-cheaper components & longer lifetime

Radiation

- especially UV-A, UV-B
- *Chemical reactions*

Wind

- *Mechanical loads*
- *Soiling*



Aerosols

- Salt, dust, industrial emissions
- *Soiling*
- *Chemical reactions, especially on hot surfaces*

Temperature

- Diurnal changes
- frost
- *Mechanical stress*

Humidity

- Air humidity, dew, rain
- *Chemical reactions*
- *Soiling*

Sandstorms

- *Abrasion*

Abrasion due to sandstorms

- Durability tests of new products by outdoor exposure take too long
- Accelerated aging tests in the laboratory are used
- Analysis of wind speed and flying sand concentration analyses
  - Operation parameters for laboratory tests

Sandstorm chamber

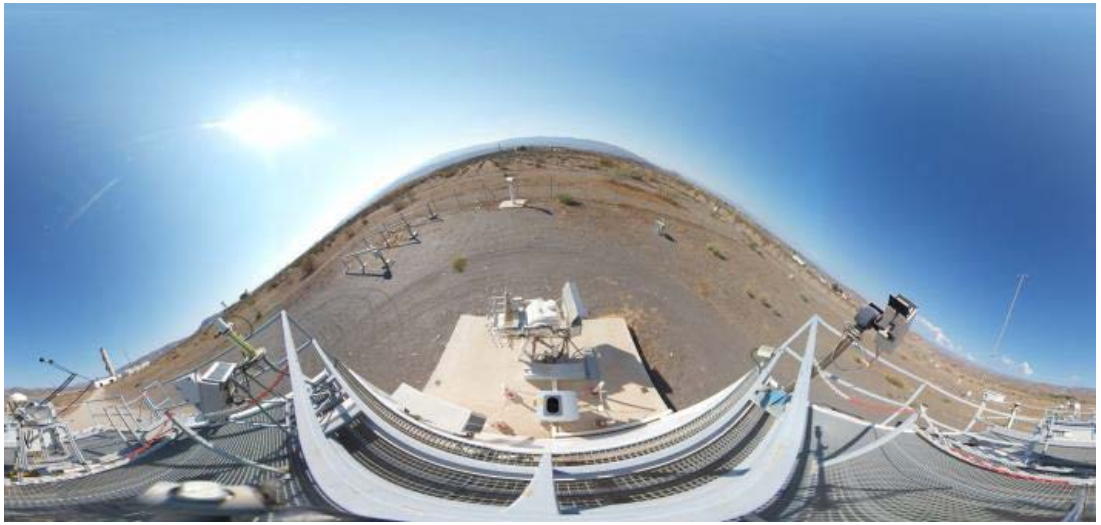
Sandstorm chamber

Meteorological Measurements for Solar Energy
Summary and conclusion

Solar irradiance is the most relevant parameter, but several other parameters also have to be measured

Meteo data collection & application = **chance for energy cost reduction**
-Low data uncertainties reduce financial risk and hence financing costs
-Cost reductions due to smart site specific design
-Cost reductions due to optimized operation:
live meteo data, nowcasting, forecasting required

Thank you for your attention and for the invitation! Questions?



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